Third Quarterly Report

on

Stabilized CO_2 Gas Laser

(1 June 1967 - 1 September 1967)

Contract No. NAS5-10309

Prepared by

Sylvania Electronic Systems
Western Division
Mountain View, California

for

Goddard Space Flight Center
Greenbelt, Maryland

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FOREWORD

This report is the third quarterly engineering report summarizing the work performed under NASA Contract NAS5-10309 entitled "Stabilized CO_2 Gas Laser," covering the period 1 June 1967 to 1 September 1967. This report was prepared by the Advanced Technology Laboratory of Sylvania Electronic Systems - Western Division, Mountain View, California. It describes work performed in the Quantum Electronic Devices Department, headed by Mr. Mahlon B. Fisher. Mr. Richard S. Reynolds is the principal investigator on the program.

All the work performed under this contract was administered by the Optics Branch, NASA-Goddard Space Flight Center, Greenbelt, Maryland. Mr. N. McAvoy is the principal technical representative for the Optics Branch.

ABSTRACT

Testing and construction continued during this third quarter toward the development of a sealed-off, 20-watt, stabilized single-frequency CO_2 laser. Stability measurements on a 3-watt single-mode laser oscillator have shown frequency stabilities as high as 2 parts in 10^{10} (6 kHz) over 100 msec periods and 3 parts in 10^8 (1 MHz) over 30-minute periods. The design of a dc amplifier for use with the oscillator is presented which should provide about 10 dB of power gain. The design is also presented for the electrical console which will house the 20-watt laser power supplies and cooling system.

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1.0 INTRODUCTION

This third interim engineering report describes work performed by Sylvania Electronic Systems - Western Division in the third quarter of a program to develop a frequency-stabilized, high-power, sealed-off CO_2 laser suitable for use in a coherent optical communications system operating at 10.6 microns. During the first two quarters of this program a design was conceived for the laser which utilizes an oscillator-amplifier approach toward obtaining high stability ($1:10^{10}$) simultaneously with high power (20 watts). Two thermally stabilized and mechanically rigidized oscillator units were constructed along with the associated thermal control system. Tests were performed on both dc-excited and rf-excited laser tubes to determine the major advantages of each type of excitation technique. It was concluded during these tests that the dc-operated tubes can have greater single-mode output power than the rf-excited tubes and were selected for the proposed application.

During this quarter both dc oscillator tubes and dc amplifier tubes were constructed. The laser oscillator consists of a laser tube with an active bore length of 60 cm and a bore diameter of approximately 6 mm. The laser tube has a large ballast and utilizes platinum cathodes. The laser tube will provide polarized output by means of potassium chloride Brewster windows. The laser amplifier consists of two 2-meter long parallel tubes, each of which are double-passed to obtain approximately 8 meters of active amplifying length. When optimized, this amplifier should provide approximately 10 dB power gain. The oscillator tubes will provide approximately 3 watts of continuous power at 10 microns; stabilized in frequency to approximately one part in 10^{10}. The output of the oscillator-amplifier chain will provide between 20 and 30 watts.

During this quarter extensive tests were performed on the thermal stability of the laser cavities; and by heterodyne tests, the short-term stability between two similar laser packages has been obtained. The thermal characteristics of the cavities have been found to be adequate enough to hold the laser frequency constant to within 2 MHz for an indefinite period of time. These tests were performed in the laboratory-type environment. The short-term stability has been found to be greatly dependent upon the acoustical environment near the laser. Measurements of the short-term stability for time periods of about 100 msec have indicated frequency drifts between one part in 10^9 and two parts in 10^{10}.

A self-contained refrigeration system was designed this quarter. This system will provide closed-cycle cooling for the laser, oscillator, and amplifier tubes. The unit will be enclosed in a power supply console which has also been designed this quarter. The power supply console will contain the amplifier power supplies, the oscillator power supplies, the heater control network for the oscillator cavity, the laser output power meter, and frequency adjust electronics for the laser. The following sections describe these components in greater detail and also describe the experimental program for this past quarter.

2.0 TECHNICAL DISCUSSION

2.1 Twenty-Watt Laser System

As shown in Figure 1, the twenty-watt CO_2 laser consists of three separate packages: 1) the laser head, 2) the laser power supply console, and 3) a regulating transformer for the power supply. The laser system will operate from a 115-volt line and will require about 25 amps of line current when the laser is operating at maximum capacity. The regulating transformer will provide approximately one percent line and load regulation for the overall power supply. A few individual components in the power supply require somewhat greater regulation than the one percent figure and are individually regulated.

2.1.1 Laser Head

Figure 2 contains the electrical schematic for the 20-watt laser lead, and Figure 3 shows the assembly drawing. The details of the assembly have changed somewhat over that presented in the second quarterly report. The amplifier has been changed from a one-tube to a two-tube system, thereby doubling the effective length of the unit, and both the amplifier and oscillator have been converted from rf-excitation to dc-excitation.

The new laser oscillator tube utilizes a platinum cold cathode fabricated in a re-entrant configuration to reduce the effects of sputtering (see Section 2.3.3). A large ballast tank is also included to increase the operating life of the laser. No life tests have yet been made on the new tube design; however, based on previous experience, lifetimes in excess of 500 hours are expected. The bore diameter of the laser tube has been reduced from 8 mm to 6 mm to ensure single mode operation and increase the effectiveness of the liquid cooling which surrounds the bore. This configuration has provided more than 3 watts single mode, utilizing an 8% transmission multilayer dielectric output mirror. Power outputs of 3 watts or greater will be sufficient from the oscillator. A liquid-cooled ballast resistor (300 kΩ) is also being used in order to decrease the laser warm-up time and

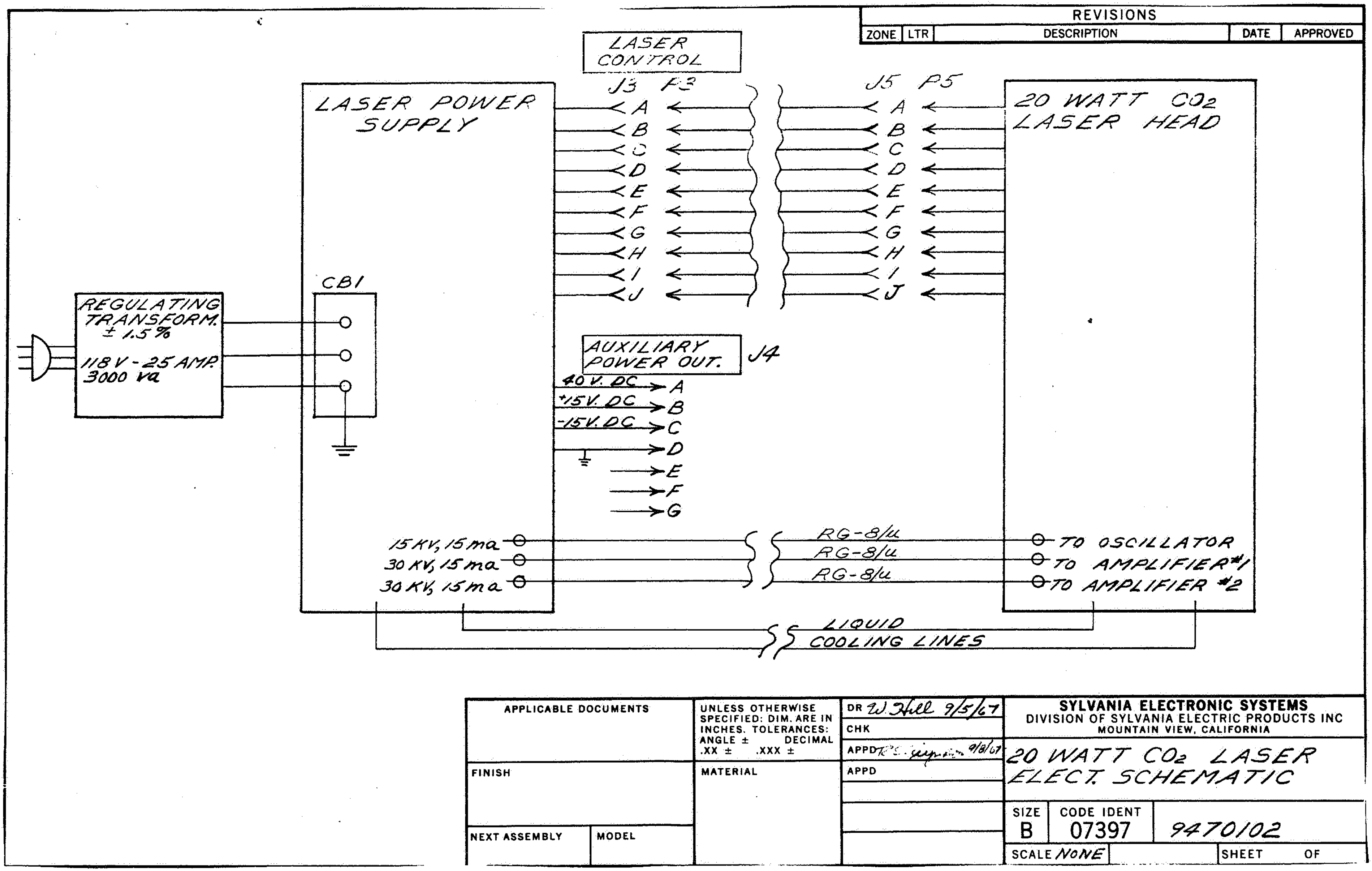

Figure 1. Electrical Schematic of Twenty-Watt Laser.

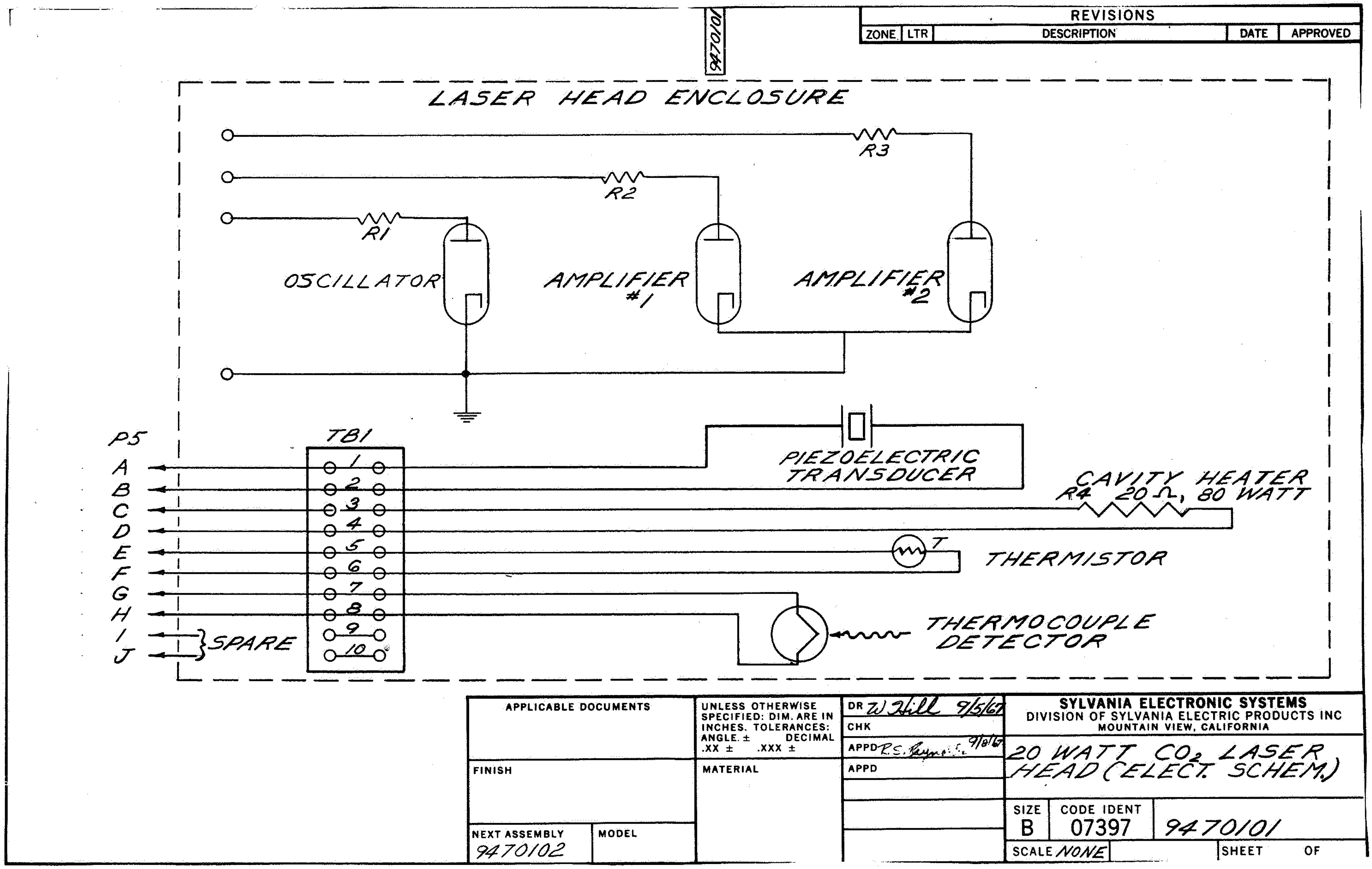

Figure 2. Electrical Schematic of Twenty-Watt Laser Head.

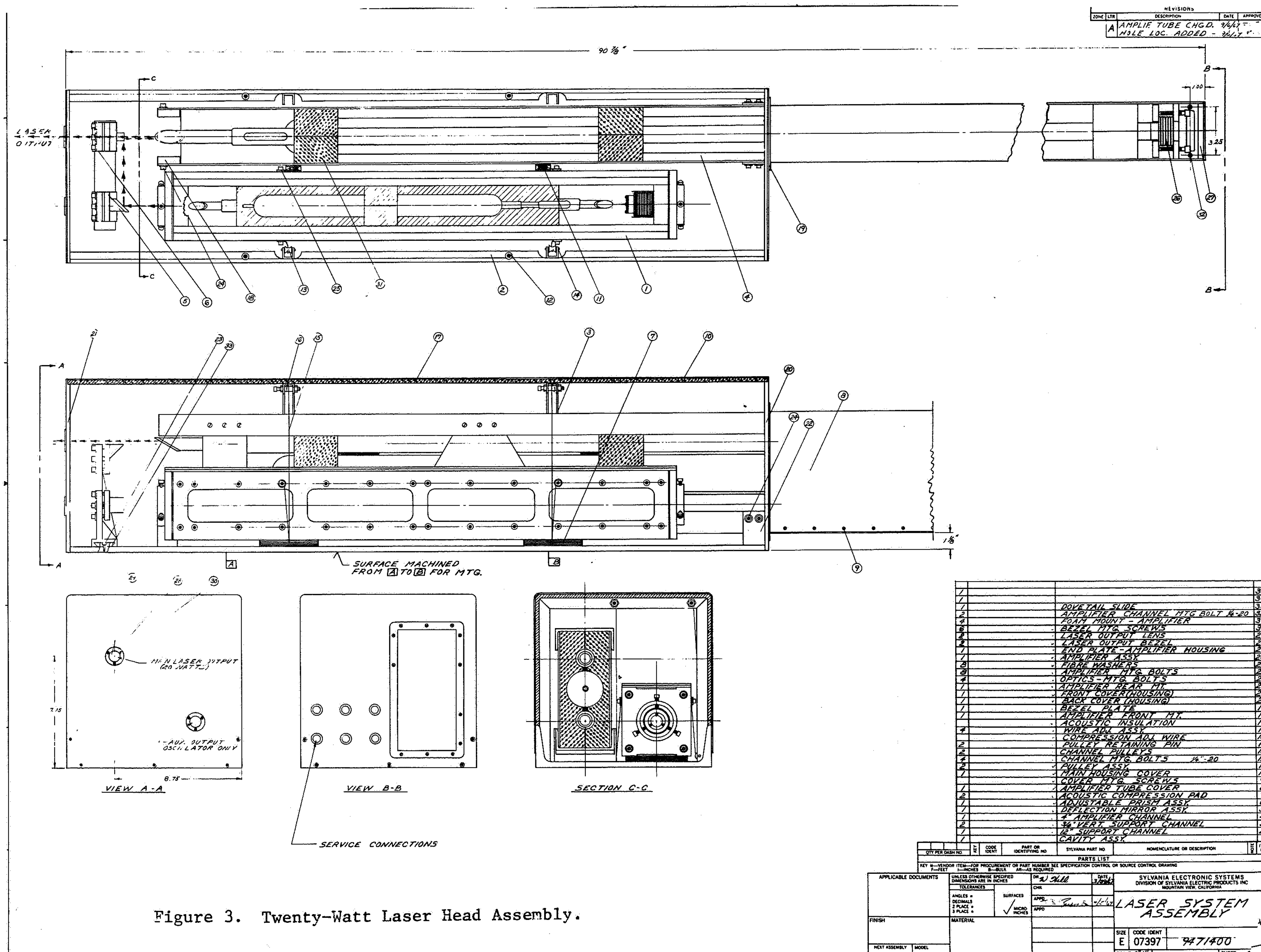

Figure 3. Twenty-Watt Laser Head Assembly.

increase the electrical stability of the laser. Stability tests between two similar laser oscillators have been performed and are described in Section 2.3.1.

The amplifier system consists of two parallel tubes connected to a common cathode and ballast tank. Figure 4 is an assembly drawing of the amplifier. Each amplifier tube is driven by its own power supply so that each tube can be operated separately. The excitation level of each tube can be controlled at the power supply to provide virtually any level of amplification up to the maximum value. Each tube is double-passed by the oscillator beam by means of the optical system located in front of the amplifier tubes and the totally reflecting mirror which is mounted inside each amplifier tube at the flanged end. The radii of curvature of the internal mirrors are chosen to provide the proper spot size at the output of each tube. The oscillator beam is introduced through the Brewster angle windows, slightly off-axis so that no interference between input and output beams will occur.

The bore size of the amplifier was chosen to be 19 mm in order to optimize the gain[*] while still maintaining a relatively large bore diameter to prevent beam vignetting. The active length of each amplifier tube is 183 cm, making a total length of the amplifying medium of 732 cm. If the amplifiers exhibit the approximately sealed-off maximum gain[*] for this bore size of .40/meter and the total loss per pass due to imperfections in the Brewster windows and losses in the mirrors can be kept to five percent, then the maximum power gain of the two-tube amplifiers will be 11.1 dB or a factor of 13. It is expected, however, that the losses in the windows and mirrors will slowly increase with time reducing the overall gain of the unit. If the overall gain of the dc amplifier tube falls to a very low 20 percent per meter with time, the overall power output can be maintained above 20 watts with a 3-watt oscillator.

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[*] P. K. Cheo and H. G. Cooper, "Gain Characteristics of CO_2 Laser Amplifiers at 10.6 Microns," IEEE J. Quant. Electr. QE-3, 79 (February 1967).

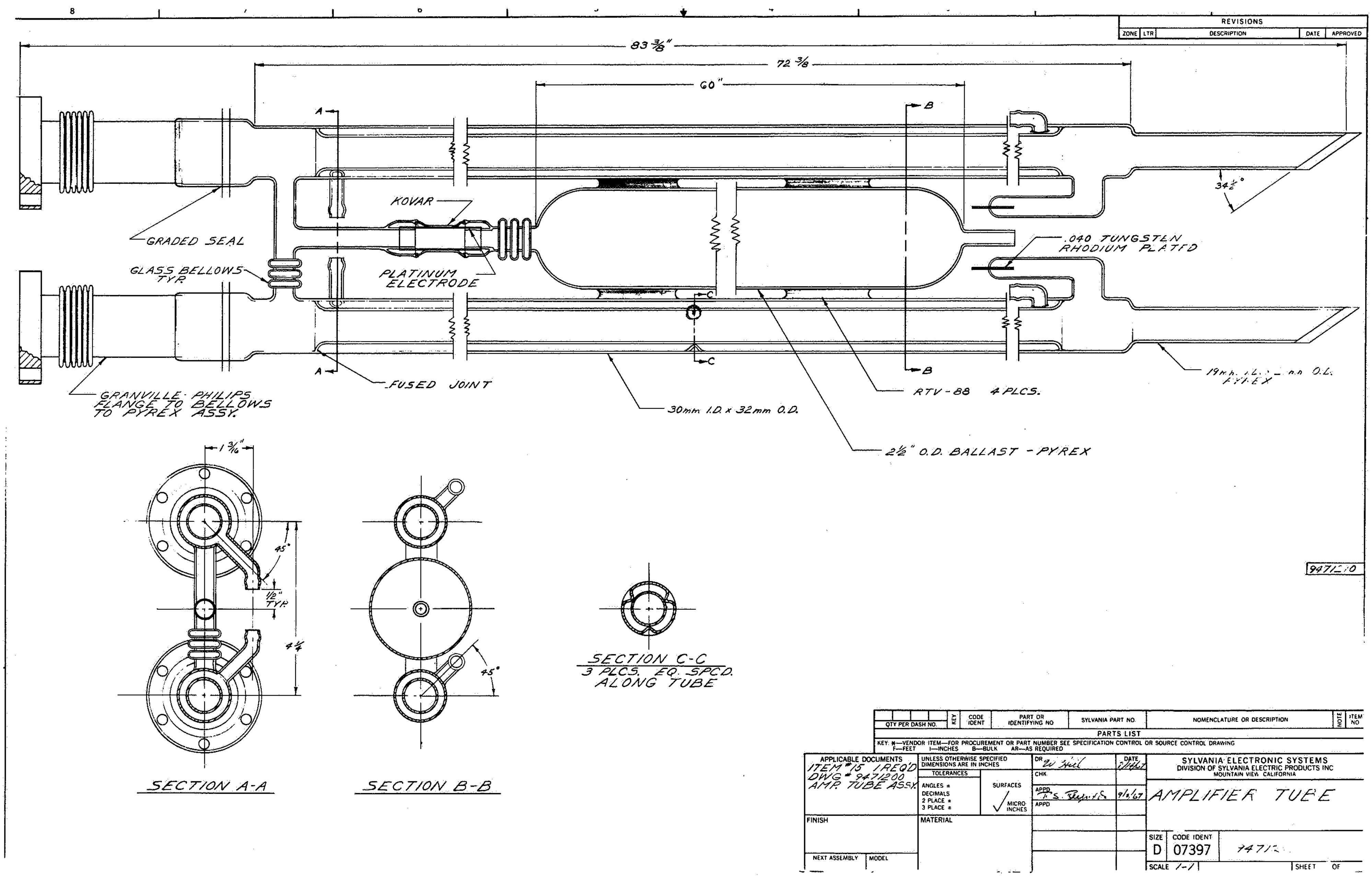


Figure 4. 10 dB Laser Amplifier Tube.

Even with this large safety factor in gain, we have included a common platinum cathode in the amplifier system to extend the life of the tube. The design of this cathode is the same as for the oscillator tube. Also a 3-liter ballast tank has been included to reduce the effects of gas clean-up due to electrode sputtering and to provide mechanical rigidity to the smaller diameter amplifier tubes.

Construction of the amplifier tube has just been completed, but no test results have yet been obtained. The rf driven amplifier tested during the previous quarter has shown gain figures close to that obtained by other researchers (28% per meter), and it is expected that the dc gain figures available will also accurately apply. The laser head is designed to be mounted on the side of a telescope in such a manner that the major weight of the laser will be located at the mounting pad of the telescope. The lightweight amplifier tubes will extend to the end of the telescope housing and will require a support pad under the mirror adjust region. Mounting points have been provided for this on the bottom of the amplifier support structure.

2.1.2 Laser Power Supply

The 20-watt laser power supply shown schematically in Figure 5 consists of a console which measures 69 inches high, 27 inches deep, and 23 inches wide. The console will house the dc power supplies for the oscillator tube and each amplifier tube, the thermal control network, piezoelectric transducer power supply, laser and amplifier heat exchanger, and a laser power readout monitor.

The laser power readout head will be located in the laser head and will continuously measure the radiation out of the last amplifier. The readout head consists of a sensitive thermocouple capable of providing enough voltage to drive a standard 100 mV dc meter. The readout meter will be located on the front of the control console.

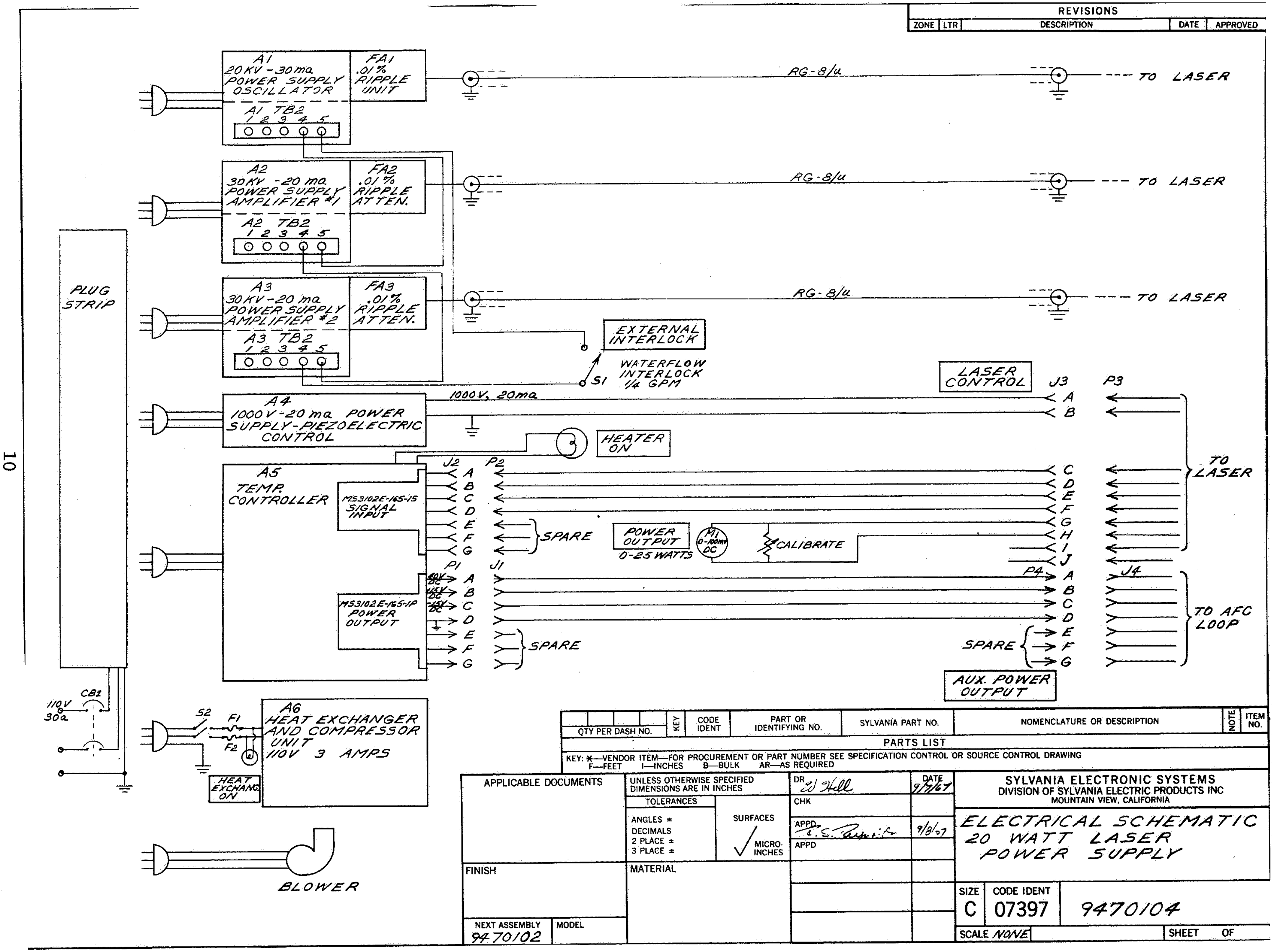


Figure 5. Electrical Schematic of 20-Watt Laser Power Supply.

The dc power supply for the laser oscillator is a Sorenson Model 1020-30 which is capable of providing 20 kv at 30 ma. Actually, with the latest oscillator design, the laser tube will only require about 15 kv at about 10 ma, so the power supply will only be operating at about 1/3 of its capability. The amplifier tubes will use the Sorenson Model 1030-20 supplies which are capable of providing 30 kv at 20 ma. It is expected that each amplifier tube will operate at a supply voltage of 25 kv and a current of 15-20 ma.

Each of the high voltage power supplies are filtered to provide a $\pm.01\%$ ripple at 60 cps. The line and load regulation for these units are provided by the regulating transformer which electrically precedes the console. The power supplies are fully metered so that the current and voltage can be monitored, if desired. Over voltage and current interlocks are included as well as coolant flow and temperature interlocks. Fuses are easily accessible on the front panel.

The heat exchanger and liquid cooling system will require about 1/3 of the volume of the console. Figure 6 is a flow diagram of the cooling system which includes an air-to-freon compressor-condensor system and a freon-to-ethylene glycol heat exchanger. The ethylene glycol (Prestone) antifreeze system has been used to ensure that the water cooling system used on the laser side will not freeze if the cooling system is inadvertently left on. The compressor system has been chosen to allow operation of the laser at lower than ambient temperatures, so that higher gains in the amplifiers and greater output from the oscillator can be achieved if necessary. The compressor system utilizes an automatic temperature control unit which allows operation at any point from -25°C to room temperature under no-load conditions. However, with the full load of the laser head, it is not expected that temperatures below about 0°C will be possible.

The freon system utilizes a continuously operating compressor. Temperature control of the ethylene glycol is controlled by the use of a bypass solenoid valve which diverts the freon liquid to an auxiliary evaporator for a fractional period of time. The proportion of time that the liquid

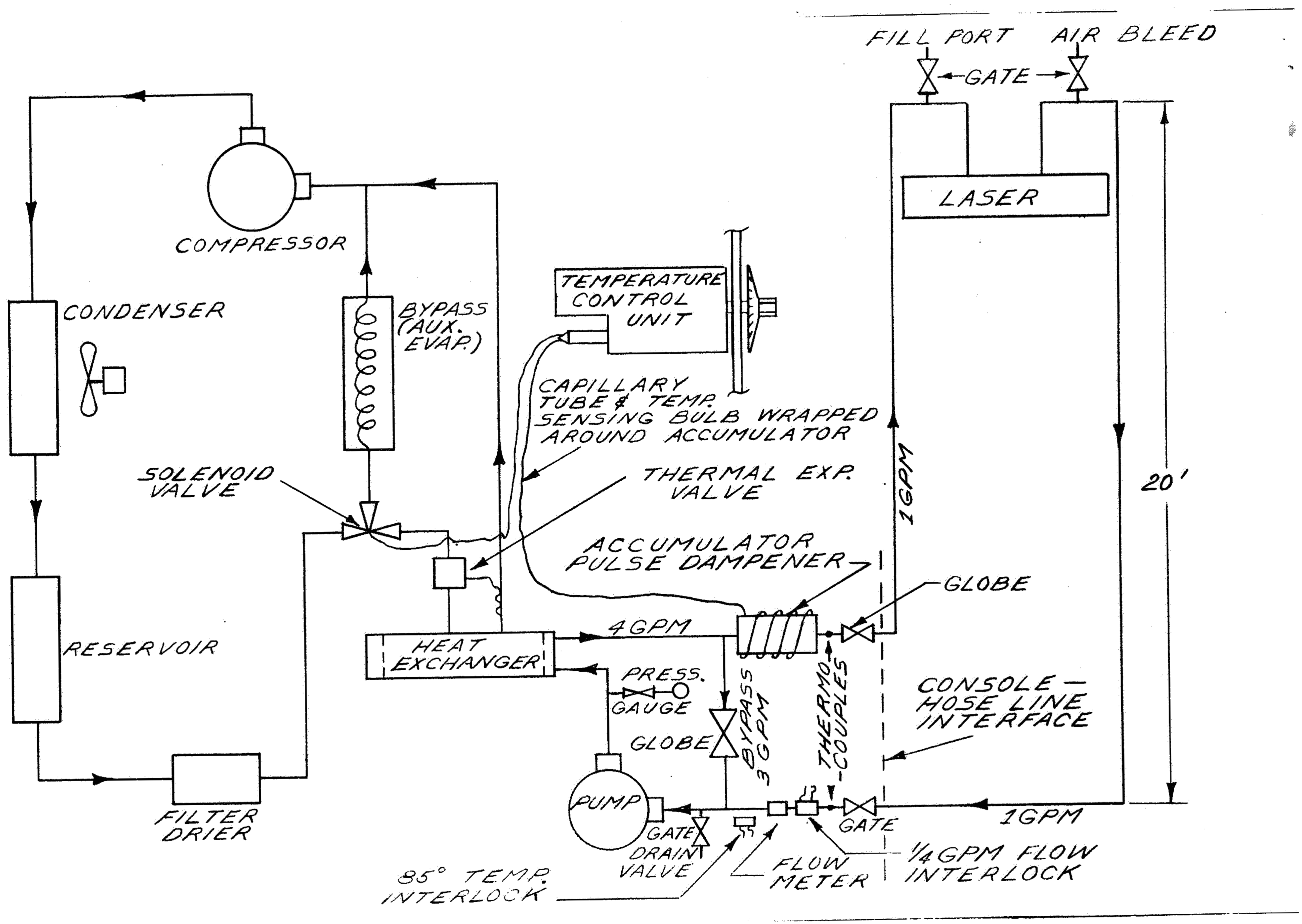


Figure 6. Twenty-Watt Laser Cooling System.

is diverted is controlled by the adjustable temperature control unit. The continuously operating feature of the compressor systems reduces current surges on the line which could be reflected in the laser output through the dc power supplies.

The antifreeze side of the system utilizes a centrifugal pump capable of delivering about 4 gpm for the size and length of lines to be used. For maximum stability and control only a portion of the flow will be used to cool the laser. Appropriate valving and interlocks are included in this side of the cooling system.

Based on the results of experiments performed this quarter (Section 2.3.1) an accumulator has been included near the output end of the pumping system. Vibrations introduced by the pump and by turbulent high velocity flow can be coupled into the laser and appear as short-term frequency fluctuations on the laser output. The accumulator, which serves as a pulse dampener by decreasing the velocity of liquid, substantially reduces the vibrations from the pump. Also the lines from the console interface to the laser will be flexible and will tend to dampen much of the residual vibrations.

After the laser is installed in position on the telescope, the cooling lines will be filled with the antifreeze solution through valves available at the high point in the system. The percentage of ethylene glycol in water will be 40% or greater by volume which will result in a freezing temperature below that capable of the freon system.

2.2 Three-Watt Laser System

The three-watt laser system is identical to the twenty-watt laser except that the three-watt laser contains no amplifier, no self-contained heat exchanger and no built-in power meter. Figure 7 shows schematically the entire three-watt system. In order to maintain maximum flexibility, the components in each laser system are completely interchangable.

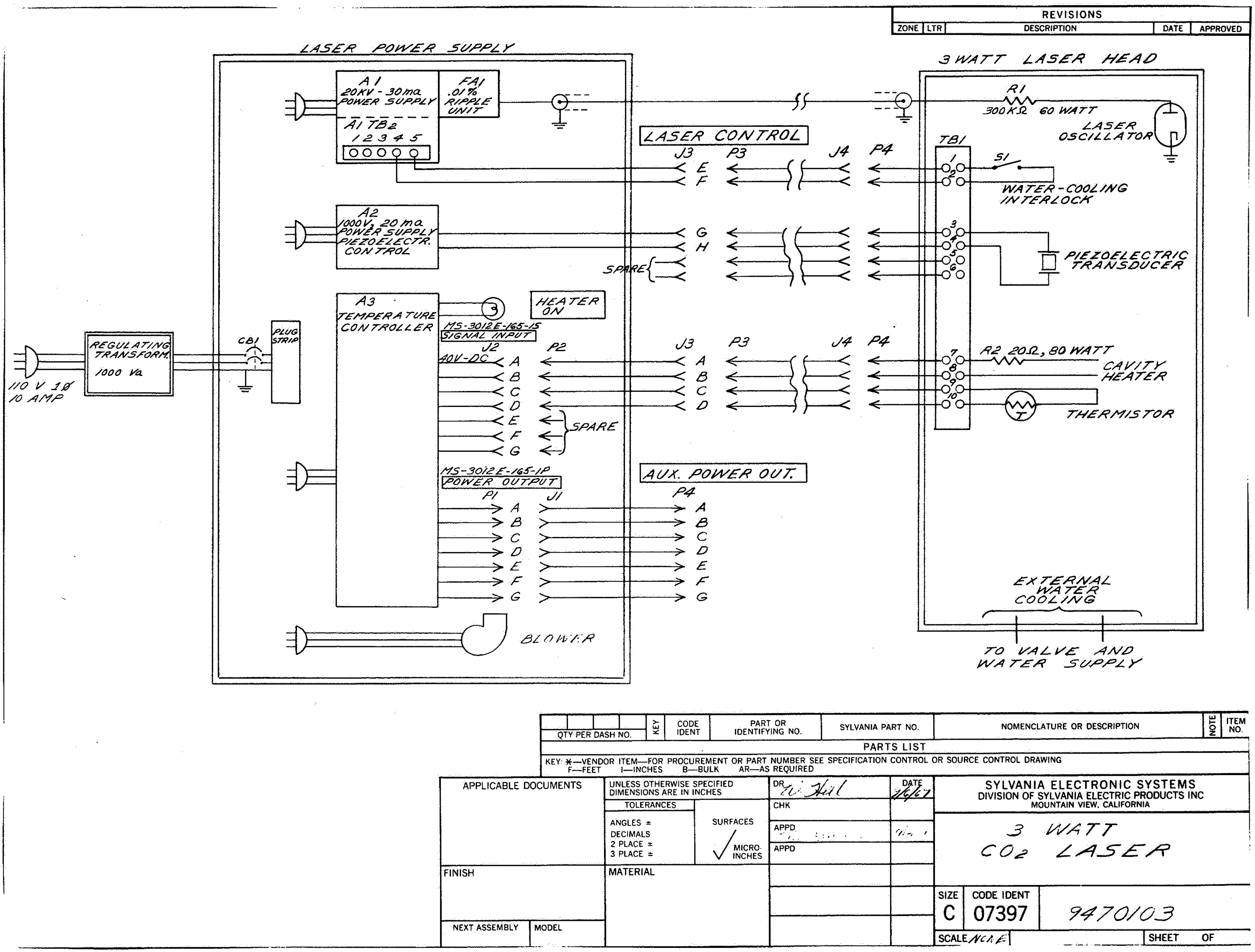


Figure 7. Electrical Schematic of Three-Watt CO_2 Laser.

To insure that the unit is not operated without water cooling, a flow interlock will be included within the oscillator package. The interlock will prevent the dc supply from being turned on unless water is flowing. The laser head measures 48 inches long by 12 inches square. The oscillator cavity will be installed in the center of the 12-inch wide support channel (see Figure 3) and will be surrounded with acoustical padding. The laser temperature will be controlled with an identical temperature control unit as installed in the 20-watt laser.

The power supply console for the 3-watt laser is a bench size unit and measures 30 inches high by 19 inches deep by 23 1/2 inches wide and will weigh approximately 150 lbs.

2.3 Experimental Tests

2.3.1 Heterodyne Stability Tests

During the last quarter experimental data were taken on the long- and short-term frequency drift between two laser oscillators. Both oscillator cavities were identical; however, one laser tube was dc-excited while the second laser tube was rf-excited. Both tubes had Brewster-angle windows with external mirrors. The dc tube had a bore diameter of 8 mm, while the rf tube had a bore diameter of 19 mm. The multimode output power from each tube was substantially different. The rf tube emitted approximately 6 watts multimode, while the dc tube emitted approximately 3 watts. Both tubes required an additional aperture within the laser cavity to obtain single-mode operation. In both cases a 6 mm aperture was required. The mirror configuration for both lasers consisted of a flat output mirror, multi-layer-dielectric coated and a 3-meter radius of curvature gold-coated mirror on the non-output end.

Both lasers utilized liquid cooling for the tube bore. The dc tube utilized tap-water cooling, while the rf tube utilized a low dielectric-constant fluid so that the rf could be introduced through the walls of the laser through the cooling medium. The fluid which was used was Dow Corning 200 silicon fluid with a viscosity of 1.5 centistokes. A small pump and a water-to-silicon fluid heat exchanger was utilized in the cooling system for the rf tube. The single-mode output power from the dc tube ranged between 2 and 3 watts, depending on the gas fill, while the rf tube emitted approximately only 1 watt. The beams from each laser were combined by means of a beamsplitter made from an Irtran-2 substrate with a multilayer dielectric coating on one side, and antireflection coated on the back side. One of the two beams from the beamsplitter was directed to a 1 1/2 meter Jarrell Ash grating monochromator. So that the output of the lasers could be adjusted to operate on identical wavelengths, the second beam was passed through a lens onto a gold-doped germanium detector. Single wavelength operation was obtained simply by length-adjusting the optical cavity of each laser oscillator. Length adjustment was obtained by varying the voltage on a piezoelectric transducer onto which a mirror had been attached.

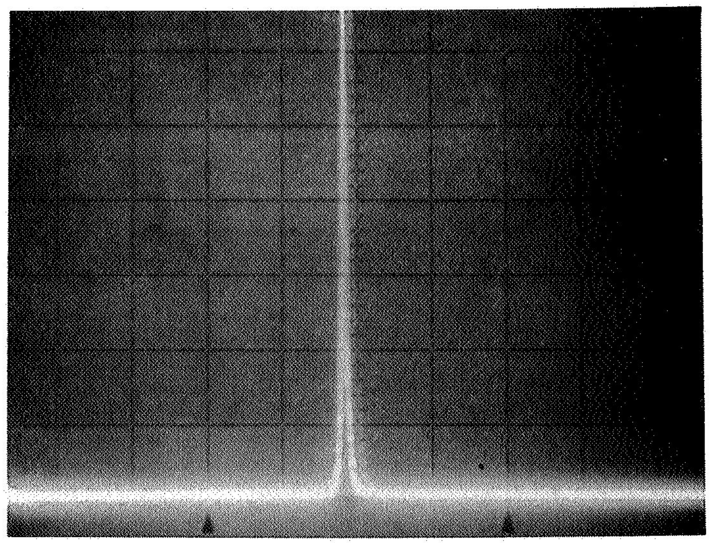
During the second quarter of the program similar tests as described above were performed, and it was rapidly determined that the thermal characteristics of the lasers were quite poor due to the incorrect bonding procedure between the invar rods and the aluminum structural cavity. During this quarter the cavities were repaired and rebonded, utilizing the RTV silicon materials as discussed in the second interim engineering report. As discussed in Section 2.3.2, this new bonding technique has proved quite satisfactory.

The heterodyne beat note generated in the gold-doped germanium detector was observed on a spectrum analyzer (Hewlett Packard Model No. 8551A), which is capable of displaying signals above 10 MHz. In most cases an upconverter was utilized (Hewlett Packard Model No. K15-8551B) which allowed observation of the beat note below the 10 MHz limit to the basic spectrum analyzer. The stability levels were obtained by noticing the rate at which the laser frequency drifted on the spectrum analyzer screen or by the width of the beat note when greater stabilities were obtained. Early stability tests resulted in stabilities of only approximately 1 or 2 MHz per second on both long and short term. The major instabilities occurred at rates on the order of one to 10 cps, and was apparently caused by air turbulence between the Brewster-angle windows and the mirrors. At the time of these tests the window area was open to the rest of the cavity, although covers were placed over the top of the laser tubes, shielding them directly from the air conditioning and other air turbulence in the laboratory. However, after the Brewster-angle air path was covered by near hermetic seals, substantial increases in stability were obtained in the 1 to 10 cps region.

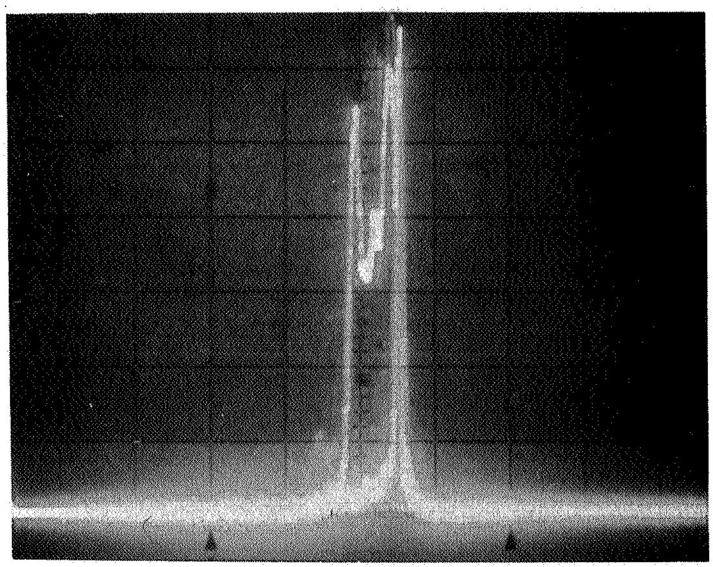
New hermetically sealed enclosures have been designed for inclusion with the final lasers. These hermetically sealed Brewster window containers will be filled with helium, and will be fabricated from metal parts so that good thermal equilibrium can be obtained within this air path. Based on further stability measurements, it is felt that instabilities caused by turbulence in this air path will be less than that caused by other effects.

Figure 8 shows typical spectrum analyzer traces of the beat note between two lasers. The beat note frequency displayed occurs at about 1/2 MHz. In both cases the acoustical environment was identical. The upper trace shows the output stability to be approximately 10 kHz per laser, assuming that each laser contributes equal amounts to the instability. The bottom trace, however, shows the stabilities to be on the order of 40 kHz per laser. These two photographs show the approximate range of stability numbers which were obtained in a normal laboratory environment. Greater instabilities could be obtained by pounding on the table or creating high-level noises in the laboratory. The normal laboratory environment included the running of pumps and fans from equipment and normal voice. In both of these photographs and in all the photographs that follow, exposure times of the camera were made long enough to allow at least two traces of the spectrum analyzer. The exposure times were 1/15 of a second.

Figure 9 shows the same beat note with greater dispersion. The upper trace shows the greatest instabilities that we normally have seen, while the lower trace shows approximately the best stabilities that we have seen to date. The width of the beat note in Figure 9b is approximately 12 kHz wide. If each laser is indeed contributing the same amount of instability, then the approximate stability of the laser is 6 kHz or about two parts in 10^{10}.



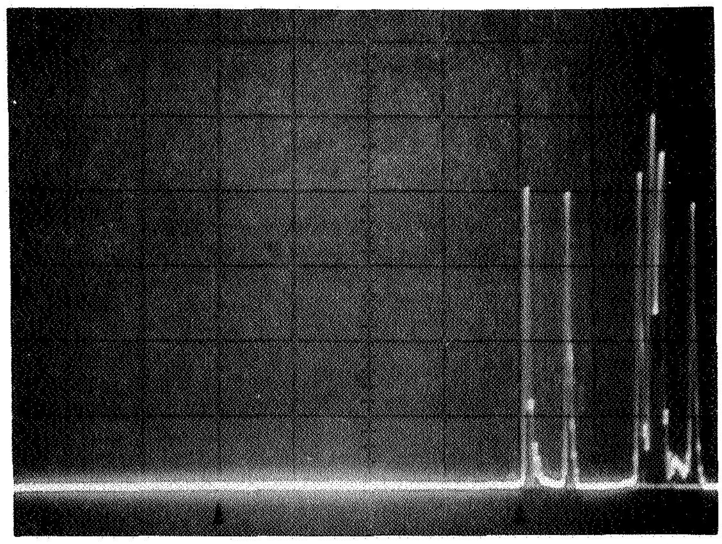
A.



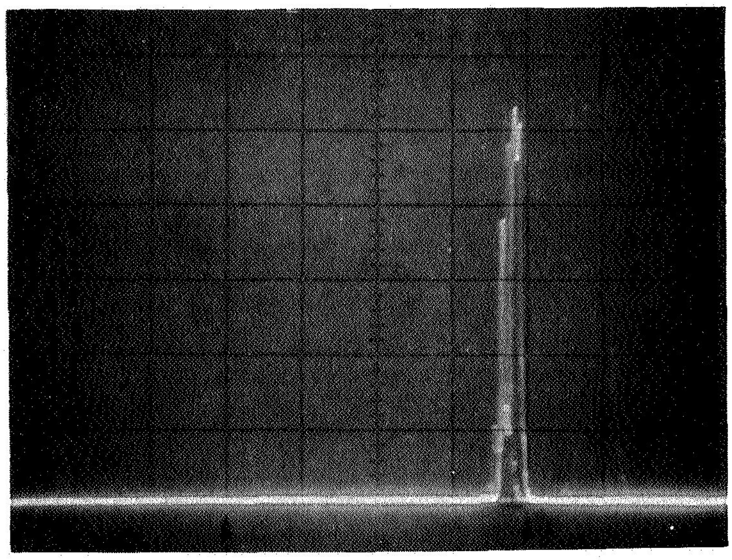
B.

Vertical Scale: Linear
Horizontal Scale: 100 kHz per Major Division

Figure 8. Spectrum Analyzer Display of Heterodyne Beat Frequency from Two CO_2 Lasers.



A.



B.

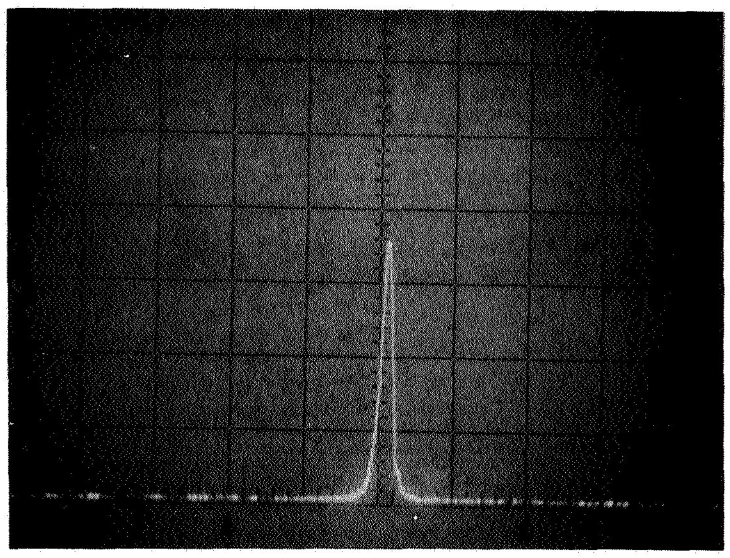
Vertical Scale: Linear
Horizontal Scale: 30 kHz per Major Division

Figure 9. Spectrum Analyzer Display of Heterodyne Beat Frequency, Showing Short-Term Stabilities Ranging from Approximately 40 kHz to 6 kHz per laser.

When greater stabilities are achieved with the lasers, the measurement techniques which have been used may require modification to achieve adequate resolution. Figure 10 shows the width of a pure signal output from a General Radio Model 1001 A oscillator set at 1 MHz. The displayed width of this nearly pure sine wave at half height is approximately 6 kHz, which indicates that the analyzer resolution may limit accuracy of the stability measurements. Narrow-band wave analyzer techniques may be required in the future.

We have found that some quieting of the beat note could be obtained by turning off the dc 200 liquid cooling system. Vibrations in the cooling system apparently were causing the major short-term instabilities. However, accurate measurement of the quieting was not possible because of rapid thermal run-away of the beat note when the cooling system was shut down. It appears that the major instabilities are due to the vibration induced in the cooling system due to the external pumps. Turning off the water supply to the dc tube did not substantially increase the stability; however, turning off the pump on the rf laser did substantially increase the stability. Steps are now being taken to include accumulators in this line so that the high frequency vibration can be damped out. An accumulator has also been designed into the final liquid cooling system which will be used with the 20-watt laser on the telescope. Some tests have been performed on damping effects on an accumulator in the pump line, and there is a substantial decrease in the vibrations which can be felt. However, no data has yet been taken on the heterodyne system.

The long-term frequency drifts due to thermal fluctuations have been much better than expected. The beat frequency between lasers has remained within a 1 MHz band for periods from 20 to 30 minutes, with peak drift rates of approximately 300 kHz/min. Also once the proper operating conditions for the laser have been set, i.e., current, piezoelectric transducer voltage, water flow, etc., the laser can be turned off and on without changing wavelengths. The rf tube has proved to be somewhat superior in its thermal



Vertical Scale: Linear
Horizontal Scale: 30 kHz per Major Division

Figure 10. Spectrum Analyzer Display of GR-1001A Oscillator at 1 MHz.

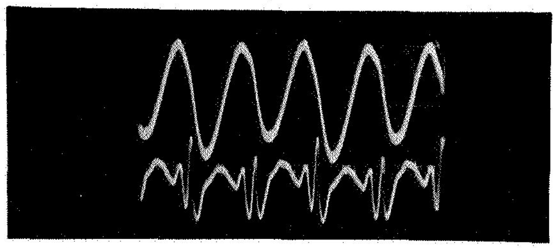
characteristics than the dc tube, primarily because the laser discharge occurs entirely within the liquid cooling jacket. In the dc tube the anode and cathode electrodes are outside the water-cooling jacket and, therefore, a temperature surge does occur when the tube is turned off and on, resulting in approximately 1/2 hour warm-up time to reach the exact equilibrium operating conditions. The rf tube, however, comes to equilibrium within only a few minutes of turn-on. The above results are for the case when the laser heating and control network are left on to operate continuously.

During the course of the heterodyne measurements a high-frequency oscillation was noticed in the output amplitude of the dc laser. This oscillation, shown in Figure 11, was duplicated on the laser driving current as well as the laser output. The modulation frequency occurred at about 9 kHz with a modulation depth of about 6%. This type of oscillation has been noticed on other types of laser tubes and is usually caused by an RC oscillation associated with the capacitance of the power supply cables and the resistance of the laser. In an attempt to reduce the magnitude or increase in the frequency of the oscillation to the point where the laser output could not follow it, varying lengths of power supply cables and several values of ballast resistors were tried with the laser. The net result was only a slight decrease in amplitude and a very small shift in oscillation frequency. However, it is found by changing the laser pressure by only a small amount caused the oscillations to disappear, both on the laser output and on the power supply current. The cause of this spurious oscillation is still not well understood, but it apparently can be controlled.

2.3.2 Laser Thermal Tests

The original laser temperature controllers utilized a bridge network in which a reference resistor was made variable so that the operating temperature of the laser could be adjusted over approximately a 20°C range. The variable resistor was found to have a rather large temperature coefficient of resistance which created a best obtainable temperature stability of a cavity of about $\pm .2°C$. This variable resistor has now

← Increasing Time



Upper Trace:	Ripple on 10 Micron Output (2 mv/div.)
Lower Trace:	Ripple on Laser Current (0.2 ma/div.)
Horizontal Scale:	50 μsec per division

Corresponding Percentage Laser Output Ripple:	6%
Corresponding Percentage Laser Current Ripple:	6%
Ripple Frequency:	9 kHz

Figure 11. Typical Oscilloscope Trace Showing High Frequency Oscillations on Laser Output and Current for Some Values of Laser Tube Pressure.

been replaced with a fixed film resistor which allows operation of the laser at only one temperature, chosen to be optimum for thermal loss characteristics desired in the cavity. The new temperature stabilities which we have been able to obtain have been better than $\pm.05°C$ over a period of longer than one day. This increase in thermal stability of the laser cavity may account in a large part for the increased thermal stability of the output frequency from the laser. If the laser cavity is cold, the warm-up time to reach stabilities of better than .1°C is approximately two hours. The operating temperature of the laser cavities has now been set at approximately 47°C . The heat loss to the surrounding ambient air and water or liquid cooling jacket of the laser requires approximately 50 watts of heater power.

A new dc laser has been designed which will reduce the warm-up time when the laser is turned on. At present the warm-up time is approximately 1/2 hour, however, the new tube should allow thermal equilibrium to be obtained within approximately 5 to 10 minutes after turn-on.

2.3.3 Cathode Studies

Some success has been achieved in increasing the life of CO_2 laser by the inclusion of platinum cathodes in dc laser tubes*. The platinum serves as an electrode with a very low reaction rate with oxygen. The low chemical reaction rate of platinum inhibits the dissociation of CO_2 into CO and oxygen and also inhibits the further dissociation of the CO into carbon and oxygen. However, platinum is known to have a rather high sputtering rate, and absorption type pumping can be rather large for platinum unless special precautions are taken in the design of the electrode. During this quarter we have tested several platinum electrode configurations in an attempt to design a platinum cathode with low relative pumping effects due to sputtering.

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*Information relative to this topic was presented informally at the Electron Device Research Conference, Montreal, Canada, June 1967.

Figure 12 shows a re-entrant type structure which we have tested at emission current densities comparable to those used in the lasers for this program. In this case the platinum sleeve is inserted within a kovar glass-sealing joint which allows electrical contact to the outside of the vacuum system. The design of the glassware on either end of the platinum is such that the discharge must occur on the inside surface of the platinum and cannot occur on the edges. Therefore, the platinum which is sputtered from one side of the cylinder is deposited on the other side. Any of the trapped gases which occur during the sputtering process can be re-liberated by the re-sputtering of the platinum. Eventually, some platinum is sputtered onto the glass structure and is lost to the system; however, this process is relatively slow, allowing a decrease in the rate of gas consumption within the laser tube compared to other electrode designs. The electrodes which were tested did not have the re-entrant type seal on the back side of the electrode, and in the early part of the tests the discharge did not attempt to take place off of the back side of the electrode. However, as the electrode became processed over a period of several days, the discharge slowly crept from the front side of the electrode to the back side during which time great amounts of sputtered material were liberated from the platinum, and the tube pressure and tube current and voltage characteristics changed rather rapidly. The first electrode which was tested utilized a one-inch diameter platinum cylinder. The electrode was attached to one end of a discharge tube without any Brewster-angle windows. The current and voltage characterisitics and the pressure of the tube were monitored during the period of operation. We found for the one-inch diameter electrode that the discharge tended to run off of only a very small area inside the platinum cylinder. At tube pressures well below the optimum for a laser operation, the discharge could be made to occur over the entire inside area of the platinum. However, at the tube pressures which are required for laser operation, somewhere near 10 to 12 Torr total, the discharge was too confined, not allowing a uniform sputtering over the inside of the platinum structure.

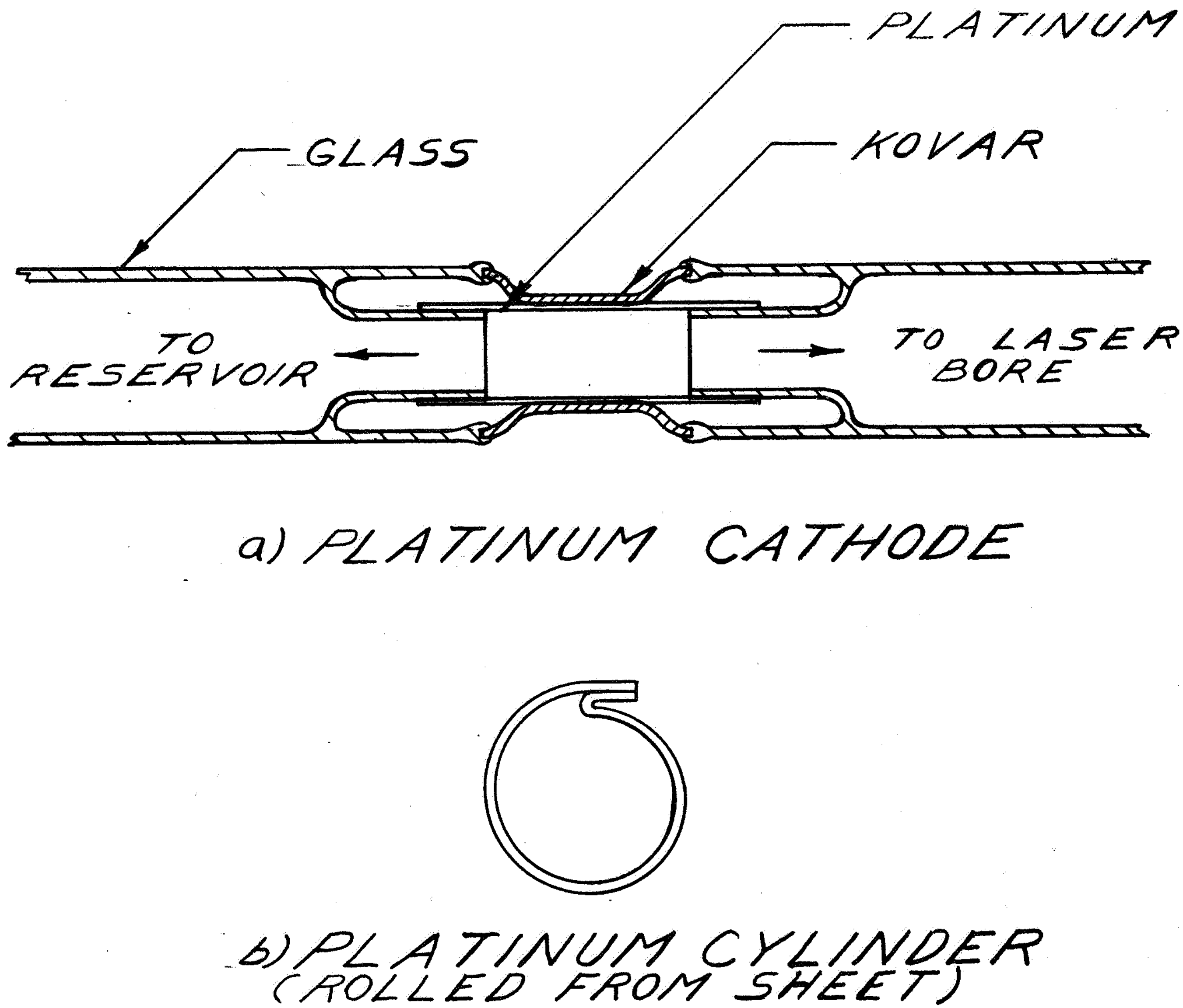

Figure 12. Re-entrant Platinum Cold Cathode.

A new electrode was then designed which utilized a 1/2-inch diameter by 2 inch long platinum cylinder. During the early testing this electrode also only emitted over a small portion of the inside diameter. However, as the electrode was run for a period of several days, the discharge tended to grow larger in area and finally covered a symmetrical, cylindrical region inside the platinum cylinder. The discharge continued to run in this manner for a period of several more days until the discharge finally grew to a size which was equal to the inside area of the platinum, and the discharge tended to run off the back edge of the platinum, creating a high sputtering rate. The electrode design in Figure 12, however, will inhibit the sputtering rate because of the double re-entrant feature. The results of the above tests indicate that a platinum cylinder approximately 1/2 inch by 2 inches long is adequate for operation of currents in the 10 to 20 milliamp range. To obtain an emission off of the entire inside surface of the 1-inch diameter by 2-inch long platinum electrode, a current of greater than 50 milliamps is required. The platinum electrode design, as shown in Figure 12, has been incorporated in the latest dc tubes. These new dc tubes also have approximately 300 cubic cm of ballast volume which should result in laser tube lifetimes exceeding 500 hours.

3.0 SUMMARY AND CONCLUSIONS

During this quarter the conversion from rf to dc operation of the lasers was completed, and the power supply console to operate the lasers was designed. All of the required power supplies and associated electronics have been procured, and assembly of the console has been initiated. The 20-watt laser, which consists of a 2-3 watt oscillator and a 10 dB amplifier, will utilize a closed cycle cooling system capable of reducing the operating temperature of the laser to as low as 0°C.

The dc oscillator tubes have been redesigned to use platinum electrodes in order to ensure long life. A cylindrical re-entrant cathode design has been utilized which should reduce the effects of platinum sputtering. These tubes have been operated single frequency at about the 3-watt level.

Frequency stability measurements this last quarter have shown laser oscillator stabilities in a normal laboratory environment to be in the range of 2-13 parts in 10^{10} over time periods of about 100 ms. It appears that these stability figures can be improved by careful design of the liquid cooling system used with the laser. A new design has been completed which will substantially decrease the vibration in the cooling lines caused by the pump.

The temperature control network has been improved to provide smaller long-term temperature variations of the laser oscillator cavity. Heterodyne measurements have indicated long-term stabilities for periods of about 1/2 hour to be better than 3 parts in 10^8 with peak excursion rates of about 300 kHz per minute.

A new amplifier design has been completed which should provide a power increase of the oscillator beam of about 10 dB. The new amplifier uses two 2-meter double-passed tubes and is now dc excited. It also utilizes a platinum cathode as well as a large (3-liter) ballast volume. Construction of the amplifier unit has been completed, and it will be operated during the next quarter.

4.0 PLANS FOR THE NEXT PERIOD

During the next period final assembly of the laser units will be commenced. The amplifier system will be thoroughly tested and installed in the laser housing. Heterodyne measurements will be made at full power to determine overall system capability. With the new cooling system in operation, it is expected that stabilities of better than 1 part in 10^{10} will be achieved.

The laser units will be prepared for shipment, and the instruction manual for the units will be completed. Preparation of the final report will also be started.